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AN EXPERIMENTAL STUDY OF A TURBULENT BOUNDARY LAYER  
IN THE TRAILING EDGE REGION  
OF A CIRCULATION-CONTROL AIRFOIL

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Progress Report  
for  
Cooperative Agreement No. NCC2-545

for the period  
October 1, 1992 - June 30, 1993

Submitted to

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12 October, 1993

N94-14541

Unclas

G3/02 0187818

(NASA-CR-194522) AN EXPERIMENTAL  
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Progress Report, 1 Oct. 1992 - 30  
Jun. 1993 (Eloret Corp.) 6 p

## ABSTRACT

This report discusses progress made on NASA Cooperative Agreement NCC 2-545, "An Experimental Study of a Turbulent Boundary Layer in the Trailing-Edge Region of a Circulation-Control Airfoil," during the period 10/1/92 through 6/30/93. The study, being conducted by Jeff Brown of the Elore Institute, in conjunction with the Experimental Fluid Dynamics Branch at NASA Ames (Dennis Johnson, technical monitor), features 2-component laser Doppler velocimeter (LDV) measurements in the trailing edge and wake regions of a generic circulation-control airfoil model. The final experimental phase of the study will be carried out in the Ames High Reynolds Number Channel II (HRC2) transonic blow-down facility. During the 9-month period covered by this report, important data were acquired using the near-wall laser Doppler velocimeter (LDV) whose development has been described in previous reports. These data point strongly to the viability of this new technique for measuring the full Reynolds Stress Tensor in 3D flows.

## INTRODUCTION

Circulation control refers to the augmentation of lift on an airfoil through the tangential blowing of a high-velocity air jet over a smooth, tightly-curved leading and/or trailing edge. The tendency for such a jet to remain attached to the curved surface, known as the Coanda effect, while entraining much of the boundary layer passing over the airfoil, greatly delays trailing-edge separation and enhances lift beyond the capacity of conventional flaps. The technology could be applied to aircraft on which low take-off and landing speeds are imposed. It could also provide quick-response lift adjustments in wind-shear situations.

Circulation control (CC) technology, in general, also involves the kind of complex flow conditions that most greatly challenge those trying to (computationally) predict turbulent flow behavior. In past years,

various attempts have been made to compute the flow around generic cc airfoils, but success has been limited. One significant need seems to be a turbulence model that can perform reliably for a boundary layer subjected to the combined effects of compressibility, mass injection, strong streamwise curvature, and separation: all of which are endemic to the trailing edge flow over a CC airfoil. Presently there is a distinct lack of the experimental data that are needed to guide the development of such a model.

NASA Cooperative Agreement NCC 2-545 supports an experiment designed to provide such data. Final testing will be conducted in the High Reynolds Number Channel II (HRC2) facility at Ames, a transonic blow-down wind tunnel that allows for Mach and Reynolds numbers within the range of practical application for CC airfoils. The HRC2 has a dedicated 2-component laser Doppler velocimeter (LDV) and an electronic instrumentation patch board that links directly to a Micro-Vax computer. The Micro-Vax is connected to the Ames computer network, so data stored on it will be directly accessible to computationalists.

#### PREVIOUS WORK

Between 1988 and 1990, project work concentrated on three areas: 1) the design and fabrication of the CC-airfoil flow model, 2) the design and fabrication of a high-pressure auxiliary air delivery system, and 3) the installation of a computer-controlled, high-accuracy, 2-component laser traversing system. These tasks were described in detail in previous reports.

The airfoil model has a 23 inch chord and a 16 inch span. The leading edge is a NACA 0012 design, and the trailing edge is circular with a 1 inch radius.

The air system, to pressurize the model's internal plenum and generate LDV seed in the tunnel stagnation chamber, is designed to provide

up to one pound of air per second at 75 psi to the model and one pound per second at 450 psi to the tunnel plenum.

#### NEAR-WALL LDV

The prime motivator for the overall project is the need to develop accurate reliable turbulence models for complex flows. Near-wall data (i.e., those extending into the viscous sublayer) are essential to this pursuit. Yet there are fundamental difficulties in obtaining these data with LDV due to the high component of noise typically generated by diffuse surface light scattering. Meanwhile, hot-wire anemometry, the only plausible alternative for obtaining turbulence measurements, is unsuitable for separating/recirculating flows: the kinds of flows encountered in circulation-control applications, and for which turbulence models are most needed.

Since December 1989, Jeff Brown has collaborated with Dennis Johnson (of NASA Ames) to develop and refine a new near-wall LDV technique proposed by the latter. Ultimately, the technique would be used to make near-wall turbulence measurements in the High Reynolds II facility.

The initial phase of the collaboration concentrated on demonstrating the technique for single-component measurements in a 2D boundary layer; it was documented in reference 1. In June 1990, the LDV system was transported to a 3-dimensional boundary layer facility, on loan to NASA from Stanford University. The goal in the 3D wind tunnel has been to make accurate, reliable measurements of the full Reynolds stress tensor in a 3D boundary layer, using a two-component system, particularly near the solid surface.

#### RECENT WORK

Between June 1990 and October 1992 several modifications and refinements, described in previous reports, were made to the near-wall LDV system. They included: conversion to a 2-component system, improvement

of beam coincidence, reduction of apparent turbulence due to fringe non-uniformity, conversion to a (compact, portable) fiber-optic based system, and improvement of seeding material and technique.

In September 1992 preliminary measurements were made in the 3D region of a 60-degree wedge flow. Subsequent, and more detailed measurements were made at the same location from October to December. These measurements all showed good agreement with one another. More importantly, they captured the near-wall Reynolds stress behavior (particularly of the  $v'w'$  component) that had either been unmeasurable or measured incorrectly with the hot-wire techniques previously applied (by other investigators) in the same flow. These results encouraged the author to test the instrument in a more highly skewed and separated flow: that around a 90-degree wedge.

From December 1992 through June 30, 1993 the majority of work was performed in the following areas: The 60-degree wedge was removed from the wind tunnel, and the 90-degree wedge was inserted; a new test surface, allowing greater optical access, was designed, built and installed; optical traverse control functions were transferred to the data acquisition computer; the data acquisition software was modified to include traverse control and to facilitate data reduction and analysis; preliminary surface and flowfield pressure measurements were made on the 90-degree wedge flow; tunnel modifications were made to correct anomolous pressure distributions (i.e., asymmetries) in the 90-degree wedge flow; the wind tunnel blower motor died, requiring the purchase and installation of a new motor; surface and flowfield pressure measurements were repeated; the LDV system was reassembled after having been disassembled for tunnel modifications. Conceptual work also continued on adapting the near-wall LDV technique for experimentation in the High Reynolds Channel II facility, and on developing a system capable of measuring all three velocity components simultaneously.

## CONCLUSION

Work under NASA Cooperative Agreement NCC 2-545 during the period between 10/1/92 and 6/30/93 has focused on 3D data acquisition with the near-wall LDV measurement technique which has been described in previous reports. Work in the immediate future under this agreement will remain concentrated on the LDV technique: in particular, on acquiring and analyzing Reynolds stress data in a highly separated and 3-dimensional (i.e., 90-degree wedge) flow field.

## REFERENCES

- 1 Johnson, D.A. and Brown, J.D., "An LDV Approach for Near Wall Turbulence Measurements," presented at The Fifth International Symposium on Applications of Laser Techniques in Fluid Mechanics, Lisbon, Portugal, July 1990.